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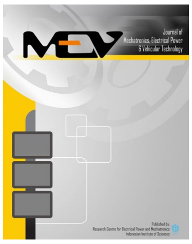

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Ergonomic analysis of gaming mouse using electromyography and subjective assessment

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Abstract

First Person Shooter (FPS) gamers usually use mice intensively, which may lead to musculoskeletal disorders. The objective of this study is to investigate the effect of the three most popular gaming mice designs on arm muscle activity and subjective perception to find the most optimum design. Subjects who participated in this study were ten healthy young adult males (age 18-24 years) selected from FPS gamers. The mice were tested when the subjects played the FPS Valorant game. The activity of forearm muscles, namely flexor carpi radialis (FCR) and palmaris longus (PL), was measured using electromyography (EMG). One-way analysis of variance (ANOVA) was used to compare the muscular activities when using the three mice. This study also measured the subjective perception of the participants. The study reveals that the high activation of muscles confirms the risk of Carpal Tunnel Syndrome (CTS). However, the difference in muscular activities between the three mice was found to be insignificant. On the other hand, the qualitative analysis suggests that the third mouse showed the evenest distribution of muscular activity both at low cycle and high cycle performance. Further study using psychophysiological methods is necessary to measure subjective preferences.

Keywords: bio-signals data acquisition; carpal tunnel syndrome; computer interfacing; e-sport; muscle activity normalization.

I. Introduction

First person shooter (FPS) is a popular computer game genre. FPS is defined as a game where the visual field of the player is representative of those of the view of the played character [1]. FPS games require fast movements, greater accuracy, and higher efficiency when using a mouse. However, fast movements increase the risk of musculoskeletal disorders (MSD) due to the physical stress in the forearm, wrist, and hand. The grip of the mouse demands coordination of bone and soft tissues to position the mouse, involving the complex biaxial motion of flexion/extension and ulnar/radial deviation [2]. In many ways, it can also be

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worsened by the lack of mental and physical training to play the demanding game. Additionally, the interface system is also crucial as the game configurations depend on players' characteristics and preferences [3].

The intensive use of mice has been associated with the risk of MSD, such as carpal tunnel syndrome (CTS), due to sustained fluid pressure in the medial nerve of the wrist [4]. In the ergonomics of the mouse, apart from the grip of the mouse, the size and consideration of table reach, positioning, mouse height, and optimal hand posturing are also critical [1]. This condition reflects the nature of the human-computer interface where the design of the mouse affects not only the immediate body parts but also other parts further away, including the other hand, due to the transfer effect [5]. The phenomenon is in line with the concept of whole-body coordination introduced by physiological anthropologists, where the coordination of hand extensor and flexor muscles around the wrist joint may affect different organs and systems inside the human body [6].

A competitive player can do at least 400 repetitive movements per minute involving great muscle activation to coordinate wrist-elbow-shoulder movement [7], with the heartbeats at the peak comparable to that of a Formula 1 driver [8]. From the literature search, there is only one study on the biomechanical effects of mouse design among Indonesian gamers, which measured the muscle activity of gamers when using a mouse, keyboard, and joystick to complete virtual manufacturing [9]. Another study is based on questionnaires distributed among gamers in Malaysia [10]. However, both studies did not specifically investigate mouse design. In other studies, most researchers investigated mice in office work [11][12], while in a study on gaming, the research emphasized multiplayer online battle arena (MOBA) games, where hand movements are dominated by low-speed, low-frequency movements, with most movements using shortcuts. This study tried to examine the effects of computer mouse design on forearm muscle activity when playing high-intensity FPS games as well as the subjective perception of the gamers to find out the most optimum mouse design for playing games.

II. Materials and Methods

A. Subjects

Participants were 10 healthy young adult males selected from their game rank (mean age 21.8 ± 1.5 years). They play an average of 5 ± 0.9 hours daily. All of them were right-handed (handedness score: +45.1 ± 14.4), measured according to a reference [13]. The participants had different preferable mouse sensitivity levels (dots per inch/dpi) as follows: four subjects had low dpi (<800 dpi), four subjects had medium dpi (800-1200 dpi), and two subjects had high dpi (>1200 dpi). All subjects were given an informed consent form to sign and return to the experimenter. The study was conducted in accordance with the world medical association (WMA) declaration of Helsinki on ethical principles for research involving human subjects.

Before the experiment, the following data of the right hand were measured: hand length, palm length, hand breadth, maximum hand breadth, hand thickness, grip diameter, maximum hand circumference, and hand circumference. Table 1 provides the hand anthropometric measurement data, presented as an average value (in cm) and standard deviation.

B. Apparatus and instruments

The experiment used the following mice: Logitech G Pro x Superlight (M1), Logitech G703 (M2), and BenQ Zowie EC2 (M3) (Figure 1). They were the three

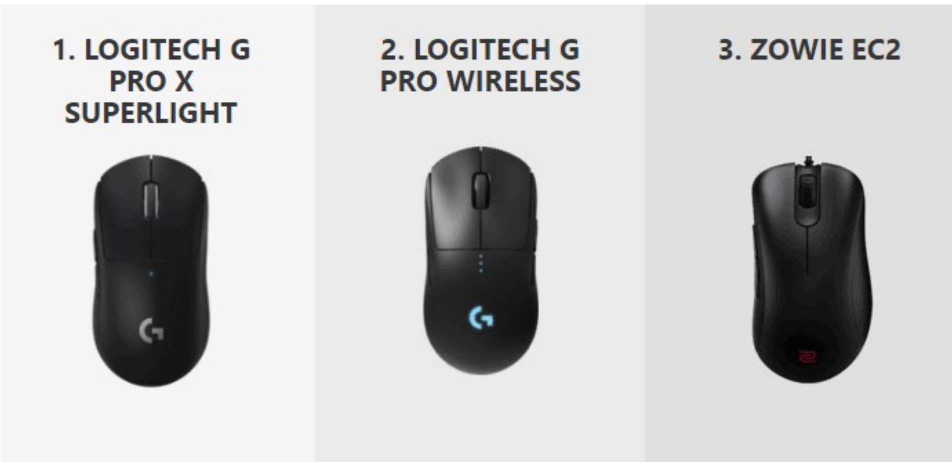


Figure 1. Logitech G Pro x Superlight (M1), Logitech G703 (M2), BenQ Zowie EC2 (M3) [14].

Table 1.
The anthropometry data of the subjects' right hand (mean ± sd, in cm).

Hand length	Palm length	Hand breadth	Max hand breadth
19.62 ± 0.94	9.83 ± 1.01	8.58 ± 0.66	12.64 ± 1.11
Hand thickness	Grip diameter	Max hand circumference	Hand circumference
3.77 ± 0.61	6.67 ± 0.47	23.64 ± 1.15	20.17 ± 0.89

most popular gaming mice reported by prosetting.net [14]. M1 is a wireless mouse that has a dimension of 125 x 65.5 x 40.0 mm^3 with a weight of fewer than 63 grams. It has a resolution of 100-25,600 dpi, maximum acceleration of >40g, maximum tracking speed of 400 inches per second (ips), and USB report rate of 1 ms (1000 Hz). It is equipped with a 32-bit ARM microprocessor and battery with 70 hours of endurance. Meanwhile M2, produced by the same company as M1, is also a wireless mouse. The specification shows that it has a dimension of 124 x 68 x 43 mm3 with a weight of 107 g. Thus, it is much heavier than M1 despite the volume being almost the same. Different from M1, M2 has rubber-covered left and right-side surfaces that ease the grip. It has a resolution of 200-12,000 dpi, a maximum acceleration of >40g, a maximum tracking speed of 400 ips, and a USB report rate of 1 ms (1000 Hz). Just like M1, M2 is also equipped with a 32-bit ARM microprocessor. However, the battery has life of 32 hours. M3 is a wired mouse produced by a different company from both M1 and M2. It has a dimension of 120 x 64 x 40 mm^3 with a weight of 90 g. Thus, it is slightly smaller in volume than both M1 and M2, but its weight lies between the weight of M1 and M2. It has a resolution of 400-3200 dpi, a maximum acceleration of 30 g, a maximum tracking speed of 130 ips, and a USB report rate of 1 ms (1000 Hz).

The mouse selection was specifically intended to play VALORANT, an FPS game developed by Riot Games Inc. (Los Angeles, CA, USA). This game is among the most common games played for esports leagues worldwide. For competitive players, in a game like Valorant with the more realistic scenario where just a few well-placed bullets will kill the opponents, or called a low time to kill, a mouse with a flawless sensor is crucial. The preference for the mouse used to play the game is based not only on objective measures such as easy to use and click but also subjective factors, which from the respondents seems to be more dominant.

The player's gestures were recorded with a video camera recorder (VCR) for post-experiment behavioral analysis. Behavioral analysis is also based on the questionnaire on subjects' mouse preferences and their playing habit, taken pre-experiment, as well as interviews to find their opinion which is conducted post-experiment. Electromyography (EMG) data were collected using Biopac MP 160 physiological data acquisition system equipped with acqknowledge 5.0 software (Biopac Systems, Inc., Goleta, CA, USA).

C. Experiment procedure

EMG data were collected from 2 muscles of the right forearm: Flexor carpi radialis (FCR) and palmaris longus (PL), identified through a palpation method [15]. Both muscles are part of the wrist flexor group, which is pivotal when using a mouse. The muscles extend from the medial epicondyle of the humerus at the proximal part of the arm to the radial side of the anterior hand connected to the second and the third metacarpals (FCR) and palmar aponeurosis at the palm of the hand (PL) [15]. To solve inter-subject variability due to the distance from the muscle fibers to the skin surface, the EMG value was normalized to maximum voluntary electrical activation (MVE) [16]. The MVE test was conducted before the experiment in three trials. The value of 100 % MVE was acquired using a muscle testing system [17]. For the FCR MVE test, the subjects were asked to perform wrist flexion on the radial side using their maximal strength while the experimenter provided maximal pressure in the opposite direction of extension toward the ulnar side. The MVE test for PL muscle was performed by having the subjects cup their hand strongly accompanied by the flexion of the wrist, while the experimenter gave the maximal pressure in the opposite direction, namely flattening the palm and extending the wrist. In the experiment session, EMG data were collected in 3 phases, namely warming up for 5 minutes, relaxation for 5 minutes, and gameplay for 10 minutes using Valorant Deathmatch Mode. The sequence of using the three mice was randomized between subjects.

The qualitative analysis includes observation of user behavior and hand gestures using the recorded video as well as interview and questionnaire with semantic differential method from very unsatisfied/(-2) to very satisfied/(2). The semantic differential was focused on the subjective perception of five specs of the mice, namely weight, dimension, grip, control, and functions accommodated in available features. The description of the results of the observation data regarding the gestures and habits in playing is categorized into two big pictures, namely how the user holds the mouse (general three types of holding mouse: palm, claw, fingertips) and basic hand movements. The most common hand gestures data were then matched with the EMG data to categorize which movements have the maximum muscle activation.

D. Data analysis

Raw EMG data were bandpass filtered between 10-500 Hz following the recommendation of the European Concerted Action on Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) [16], followed by a notch filter at 50 Hz to remove electrical noise. Among the three EMG signal feature extraction methods, namely time, frequency, and time-frequency domains, only the time domain-based root mean square (RMS) is used. For the test session, the RMS value was processed at the moving average window of 50 ms, whereas, for the MVE test, which is static, the moving average window was set at 500 ms. The reference value for 100 % MVE was based on the average peak RMS value of the three MVE tests, whereas the 0 % MVE was based on the lowest value when the subjects relaxed.

The statistical analyses were carried out using the R-programming language. Statistical analysis was started with Shapiro-Wilk to check the normal distribution of data. When the data were distributed normally, the parametric method of one-way analysis of variance (ANOVA) with repeated measures was used. On the contrary, when the data were not distributed normally, the non-parametric method of the Friedman test, followed by the Wilcoxon signed-rank test, was used. All statistical tests use the significance level of $p<0.05$.

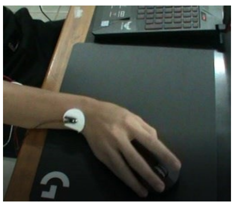
In this study, the use of qualitative analysis is to cover the subjective nature of game mouse preference as an integral part of the cause for mouse choice together with the quantitative measurement of EMG data. Qualitative research has been described as a study whose data are presented in the form of words instead of numbers [18], and the mouse preferences study is one example of a study where subjective factor probably matters more than objective ones. The data on subjective perception is represented in a radar chart created using Microsoft Excel.

III. Results and Discussions

A. Observation of participants behavior

The categorization of the most common gestures is described in Table 2. Based on the video, which was then matched with EMG data, most of the greater muscle activation was caused by radial deviation and

Table 2.
Hand gestures classification.

Movement	Picture	Description
Flexion		Flexion movement occurs when there is a vertical movement in the form of a mouse pull toward the user.
Extension		Extension movement occurs when there is a vertical movement in the form of a mouse pulling away from the user.
Radial deviation		Radial deviation movement occurs when there is a horizontal movement in the form of an inward mouse movement (to the left).
Ulnar deviation		Ulnar deviation movement occurs when there is horizontal movement in the form of mouse movement outwards (to the right).

ulnar deviation around the wrist joint, in order to aim horizontally with moderate pacing. This horizontal movement can further be classified into low and high cycles. The low cycle movement produces very little hand muscle activation, including micromotion. Micromotion occurs when the hand moves to aim at a distant target, two targets with close distances, strafing movements, or the use of long-range rifles. In the micromotion, the load of the hand is very small, with minimal wrist and elbow movement. The high cycle motion includes flicking. In contrast to micro motion, where the movement is very smooth with a low travel distance, flicking motion is the total opposite, as it usually occurs when the player aims quickly at a moving object, two or more objects that appear quickly one after another. There is constant movement from one point to another by relying on the speed and strength of the palm, wrist, or elbow. Flicking can also be called a spontaneous explosive motion with low accuracy. In addition to muscle memory, the level of flicking accuracy also depends on the neutral wrist position, which usually ranges from 0-30° (right-left), with a motion of greater than 30° resulting in lower accuracy and causing severe wrist fatigue.

B. Quantitative data on muscles activity

The EMG data are presented as both the average of peak and mean muscle activation. The average peak muscle activation represents the greatest muscle force exerted when playing the game. A single peak value is less meaningful because of the variable nature of EMG signals [16]. As such, in this study, the peak value is presented as an average peak value of several data taken during trials to make it less sensitive to analysis intervals, as suggested by a reference [16]. The average of mean value, on the other hand, together with standard deviation data, have been commonly used in EMG analysis because they represent the total muscle excitation input of the target muscle for the performed task in a certain period and therefore, considered the best for comparison analysis like in this study [16].

FCR muscle is responsible for flexion [19] and radial deviation of the hand at the wrist joint [20], two movements commonly performed when using a mouse. Anatomically, the origin of the FCR muscle is at the medial epicondyle, then attached to the second and third metacarpals [21]. Figure 2 shows the data on FCR muscle activation. The average of mean FCR muscle activation when using the three mice does not show significant differences (M1: 3.80 % ± 2.22 % MVE, M2: 3.62 % ± 1.83 % MVE, M3: 3.75 % ± 2.08 %, p>0.05). Such condition was also observed on the average of peak FCR muscle activity (M1: 39.91 % ± 17.29 % MVE, M2: 47.17 % ± 26.58 % MVE, M3: 45.14 % ± 21.20 % MVE, p>0.05). The results of this study indicate that there is no significant difference in either wrist flexion or radial deviation due to mouse design. FCR muscle has been closely associated with certain cervical muscles, so it is commonly investigated in video gaming therapy for spinal cord injury patients [22]. This muscle is also reported to be critical in hand and neck muscle coordination when using a digital board for online teaching [20]. The insignificant difference in FCR muscle activation affected by the mouse design probably indicates that the design does not influence hand-neck coordination while using each mouse for playing the FPS game.

PL muscle is responsible for various actions, namely hand flexion-extension at the radiocarpal joint, palmar aponeurosis and skin of the hand stabilization, thumb abduction, wrist abduction-adduction, and anchoring for the hand [23]. Anatomically, it is a thin muscle with a short belly and long tendon spread from the medial epicondyle of the humerus to the palmar aponeurosis and flexor retinaculum of the hand [24]. PL has been identified to be clinically related to the occurrence of CTS [25]. PL muscle activation has been reported to contribute to various gestures performed by gamers [26]. Figure 3 shows data on PL muscle activation. Just like FCR muscle activation, the average data of mean PL muscle activation against the three mice shows insignificant differences in the average mean of PL muscle activation data (M1: 5.80 % ± 1.82 % MVE, M2: 6.09 % ± 2.78 % MVE, M3: 7.38 % ± 4.80 % MVE, p>0.05). For maximum muscle activity of PL muscle when using the three mice, the statistical analysis using the one-way ANOVA statistical method also reveals the absence of significant difference in the average peak PL muscle activation data (M1: 50.66 % ± 23.38 % MVE, M2: 48.31 % ± 27.25 % MVE, M3: 51.02 % ± 29.43 % MVE, p>0.05). Previous study indicated that the knowledge of the exact functionality of PL muscle in forearm and wrist joint movement is still very limited [24]. However, its role in grip stability through its effects on the consistency of wrist flexion moment has been reported in a previous study [24]. The findings on PL muscle activation patterns in our current study indicate that the three mice do not show different effects on grip stability.

In general, the findings on insignificant differences in muscle activity of both FCR and PL muscles when playing the Valorant game using the three mice may indicate the greater variability of the subjects in movements and the limitation of the employed biomechanical approach for assessing mouse design effects on muscular activities. A previous study also reported that there is very little difference between muscle activity, hand motion, usability, and fatigue among professional gamers due to mouse design [27]. The difference was only observed when comparing the expertise levels of gamers [27]. Two previous studies are also in agreement with this study [28][29]. This study, as a pilot project, has many limitations in characterizing the movements of each subject to apply any controlling and conditioning for the experiment. The subjects were also relatively uniform in expertise level. Using a mouse is a complex activity affected by various variables such as hand posturing and the size of the stimuli [30], mouse type [27], as well as player experience [31]. In future studies, those variables should be defined accurately to develop better experiment control. The inclusion of variables such as fingertip pressure and movement speed are also necessary as they have been reported to be correlated with both shoulder and arm muscle activation level and discomfort level, especially if the movements are divided into more standardized tasks of clicking and dragging [32]. Another study suggested that the use of amplitude probability distribution function (APDF) analysis for low-level muscle activation for a longer duration in using a mouse is more appropriate [33] compared with the RMS of the present study.

C. Qualitative data of mice assessment

Subjective perception has been commonly used in design assessment, such as in the automotive industry [34]. The in-experiment observation by the experimenters was analyzed by comparison with the post-experiment analysis of the questionnaire and interview. Figure 4 shows the level of satisfaction after using the three mice. They have similar levels of control. M1 is superior in weight as it is the lightest. M2 offers better subjective features with its rubber cover on either side of the mouse, the click sensation, and the side buttons. Compared to the experimenter's observation, in general, it seems that M2 produces an output that is inversely proportional to the M1 output. However, in high cycles, the M1 mouse has the best performance due to its lightweight. M3, on the other hand, offers greater satisfaction regarding dimension and grip

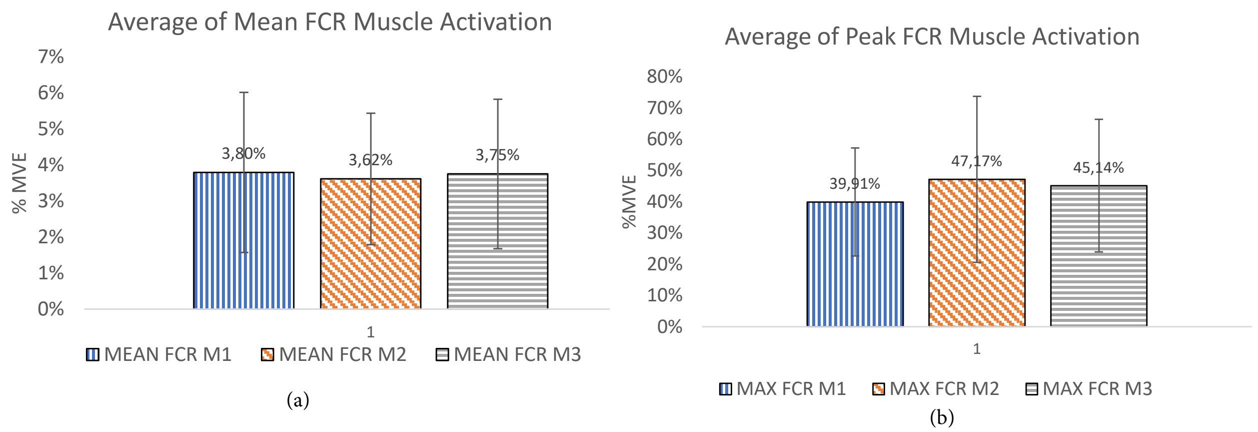


Figure 2. The average of mean FCR muscle activity: (a) and the average of peak FCR muscle activity; (b) when using the three mice for playing the game (in %MVE; mean ± SD; p>0.05). The difference of FCR muscle activation due to mouse design was found to be statistically insignificant.

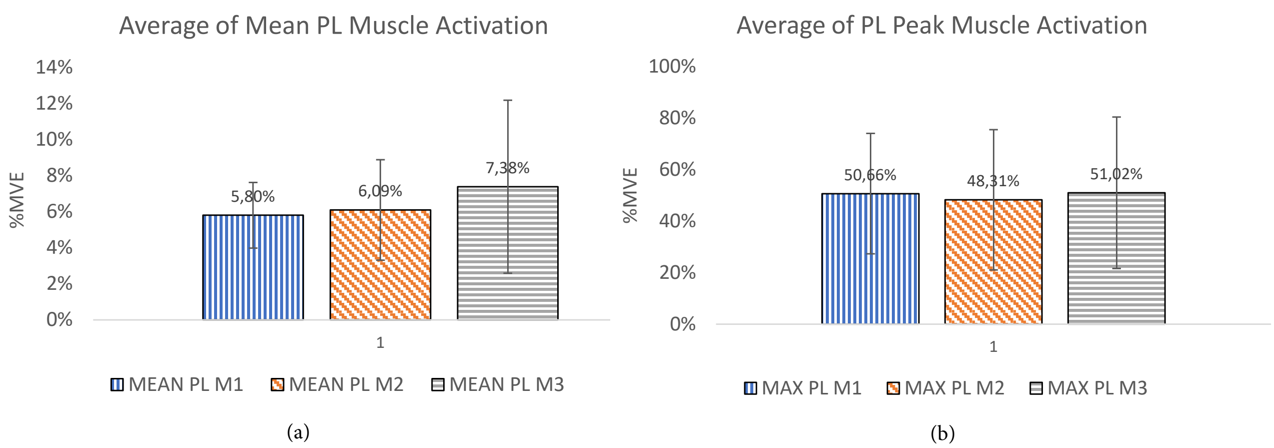


Figure 3. The average of mean PL muscle activity: (a) and average of peak PL muscle activity; (b) when using the three mice for playing the game (in %MVE; mean ± SD; p>0.05). Just like the FCR muscle, the difference of PL muscle activation due to mouse design was found to be statistically insignificant.

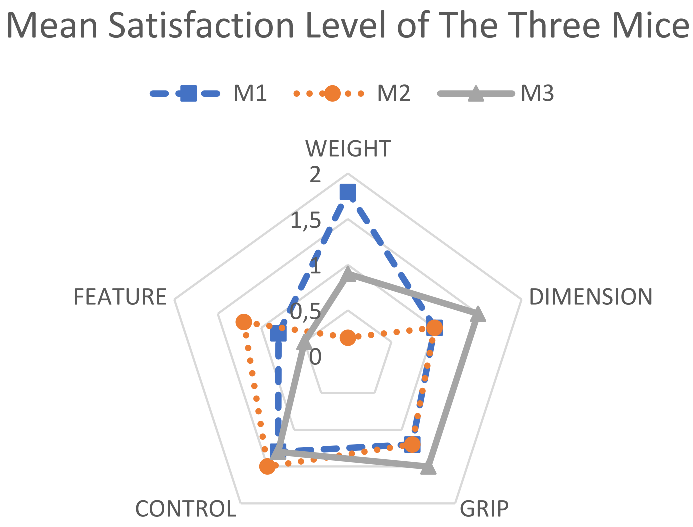


Figure 4. The subjective perception of the three gaming mice describes the level of the subjects' satisfaction.

despite inferior features. M3 is also the most balanced mouse with regard to both high and low-cycle scenarios. This mouse has a medium weight, as its weight is between that of M1 and M2, and its asymmetrical shape is very good for right-handers. Furthermore, M3 also provides various types of user grips, and it has a more asymmetrical shape which greatly considers the skewed posturing of the right palm.

Right-handers have been dominating the human population, with the percentage varying between 85 % and 90 % of the population. Consequently, most facilities in the artificial environment were designed for right-handers. Computer mouse design is not an exception. However, there are many mouse designs that are developed with the intention to be used by ambidextrous users, meaning both right-handers and left-handers can use them. Logitech has offered various mice series with ambidexterity as its main consideration, with more symmetrical shapes, such as M1 and M2. On the contrary, M3 is more asymmetrical with less ambidexterity consideration in its design, and thus, tailor-made and highly optimized for right-handers like all the participants in this study, which probably made most of them prefer M3.

The perceived advantages and disadvantages of mouse design in this study are basically a trade-off. The symmetrical shape of M1 becomes less optimum for right-handed users; however, it accommodates various types of users in accordance with universal design principles, which are getting greater acceptance in the design world nowadays [35]. Another disadvantage of this mouse is control. With the weight being too light, small control on this mouse in low cycle becomes difficult. On the other hand, this is also an advantage for far and fast movements of the high cycle. Regarding the M2, its shape, which is less symmetrical than M1 but more symmetrical than M3, has also been adjusted to the ergonomics of the right hand. However, it is heavier, so it makes high-cycle movements perceived as more fatiguing. M3 almost adopts the good parts of the two mice and has stable performance in various scenarios. This mouse also has an ergonomic shape for right-handers and is adjustable for various kinds of grips.

D. Implications

During product development, designers are often obliged to make quick assessments and decisions with limited information. Therefore, they use any tools at their disposal, either quantitative or qualitative methods [36]. A study on fashion product evaluation found that regarding comfort, while objective measures such as physiological responses can be a reference for establishing product classification, individual preferences are largely subjective [37]. As such, the study suggested that for product design evaluation, the understanding of subjects' ratings and preferences by means of an interview is a must [37]. Like that study, the present study also found insignificant differences in the quantitative method using EMG data. It was the subjective assessment based on observation and interviews with the participants that provided insight into the preference. The subjects were selected from a group of game players through a stratified random sampling method to ensure their uniformity, including their dominant hand, where all the recruited participants were right-handers, to get more significant statistical results for the quantitative approach using EMG. However, contrary to the expectation, the results were found to be insignificant.

While the EMG data do not show significant differences in wrist flexor muscle activation, this study revealed the potential for upper extremity musculoskeletal disorders in the hands, as this is evident from the presence of muscle activity that exceeds 40 % MVE, which indicates the risk to cause fatigue and musculoskeletal complaints. Thus, the three mice all have a great possibility to induce CTS in their users. Furthermore, the results of the research indicate that myoelectric activity is directly proportional to the kinematics of the hand, especially the travel distance, which is the biggest cause of an increase in muscle activation.

IV. Conclusion

While in general, based on muscle activity data, there are statistically insignificant differences due to mouse design on both FCR and PL muscle activation, the subjective qualitative analysis can be used to further find the most optimum mouse design. In this study, the third mouse (M3) shows the most evenly distributed performance in two scenarios in the game, namely low cycle and high cycle. Although graphically this mouse is not the most superior in both scenarios, this mouse is also not the worst either. This shows that this mouse is the most ideal in the FPS (First Person Shooter) game scenario. The high level of muscle activation also indicates the risk of CTS due to intensively playing FPS games. Future studies should employ psychophysiological instruments to assess the subjective preferences observed in this study.

Declarations

Author contribution

R.A. Zafs: Writing - Original Draft, Writing - Review & Editing, Conceptualization, Investigation, Validation, Data Curation. **Other Authors:** Writing - Original Draft, Writing - Review & Editing. All authors read and approved the final paper.

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Competing interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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